CORRELATION BETWEEN FOAM STABILITY AND ELECTROKINETIC SIGNAL IN FOAM ASSISTED WATER ALTERNATE GAS PROCESS

SHAZIERA BINTI OMAR

UNIVERSITI TEKNOLOGI MALAYSIA

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SHAZIERA BINTI OMAR

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To my beloved husband, son, mother and family

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ABSTRACT

Foam is purposely used in some of the Enhanced Oil Recovery (EOR) displacement processes in order to control the mobility ratio, hence improving the volumetric sweep efficiency. The efficiency of a foam displacement process in EOR depends largely on the stability of the foam films. In laboratory, foam stability is usually measured through physical observation of the foam bubble in a glass tube. Unfortunately, this direct observation is not possible in the reservoir. Therefore, indirect measurement such as the measurement of electrokinetic signal would be a better alternative. This study aimed to determine the correlation between the foam stability and the associated streaming potential signals which resulted from the flowing fluid in foam assisted water alternate gas (FAWAG) process. The downhole monitoring of streaming potential which uses electrodes mounted on the outside of an insulated casing is a promising new technology for monitoring fluid movement processes in real time. In this study, the experiments were divided into two: Foam stability test and electrokinetic signal measurement. The electrokinetic signals were measured using five non-polarizing Cu/CuCl electrodes, installed along a sand pack model and measurement was recorded continuously using NIDAS and the LabView software. Surfactant alternate gas was used to produce foams inside the porous media using five different Sodium Dodecyl Sulphate (SDS) concentrations, namely 2500, 5000, 7500, 10000 and 12500 ppm. The result from the experiment showed that 10000 ppm was an optimum concentration of SDS. Thus, the voltage (electrokinetic signal) decreased with an increase in foam stability up to optimum SDS concentration. While for 12500 ppm SDS concentration the electrokinetic signal increased as foam stability decreased. The burst of the foam bubbles had changed the pattern of electrokinetic signals. Although the voltage was small, i.e., ranging from 0 to 1 mV, it was still measureable. These results present new findings in the relationship between foam stability and electrokinetic signals generated in the FAWAG process. This fundamental knowledge can lead to developing a new approach in monitoring FAWAG processes in making the EOR process more efficient.

ABSTRAK

Busa digunakan pada sesetengah proses anjakan Perolehan Minyak Tertingkat (EOR) untuk mengawal nisbah mobiliti, seterusnya meningkatkan kecekapan sapuan isipadu. Kecekapan proses anjakan busa dalam EOR bergantung pada kestabilan selaput busa. Di makmal, kestabilan busa biasanya diukur menerusi pemerhatian secara fizikal terhadap gelembung busa di dalam tiub kaca. Malangnya, keadaan ini tidak boleh dilihat di dalam reservoir. Oleh itu, kaedah tak langsung, misalnya pengukuran isyarat elektrokinetik boleh menjadi pilihan yang lebih baik. Kajian ini bertujuan untuk mengenal pasti hubung kait antara kestabilan busa dan isyarat potensi aliran yang terhasil daripada aliran bendalir ketika berlakunya proses suntikan air berselang-seli gas berbantu busa (FAWAG). Pemantauan terhadap potensi aliran di dasar lubang menggunakan elektrod yang dipasang di luar selongsong tertebat ialah teknologi baharu untuk memantau proses pergerakan bendalir masa nyata. Dalam kajian ini, ujikaji dibahagikan kepada dua bahagian: Ujian kestabilan busa dan pengukuran isyarat elektrokinetik. Isyarat elektrokinetik diukur menggunakan lima elektrod tidak mengkutub Cu/CuCl yang dipasang sepanjang model pek pasir. Pengukuran dilaksana secara berterusan menggunakan perisian NIDAS dan perisian LabView. Surfaktan berselang-seli gas diguna dalam kajian ini untuk menghasilkan busa di dalam liang menerusi penggunaan lima kepekatan Natrium Dodesil Sulfat (SDS) yang berlainan, iaitu 2500, 5000, 7500, 10000 dan 12500 ppm. Keputusan kajian menunjukkan bahawa 10000 ppm ialah kepekatan optimum untuk SDS. Oleh itu, voltan (isyarat elektrokinetik) menurun dengan meningkatnya kestabilan busa sehingga ujikaji mencapai kepekatan optimum SDS. Selain itu, untuk SDS dengan kepekatan 12500 ppm, isyarat elektrokinetik meningkat dengan menurunnya kestabilan busa. Gelembung busa yang terletus telah mengubah corak isyarat elektrokinetik. Walaupun nilai voltan adalah kecil, iaitu berjulat dari 0 hingga 1 mV, tetapi nilai itu masih boleh diukur. Keputusan kajian mengetengahkan penemuan baharu bagi hubungan antara kestabilan busa dengan isyarat elektrokinetik yang terhasil dalam proses FAWAG. Pengetahuan asas ini boleh membantu dalam pembangunan kaedah baharu bagi pemantauan terhadap proses FAWAG dengan menjadikan proses EOR lebih cekap.

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LIST OF ABBREVIATIONS

CMC	-	Critical micelle concentration
CSS	-	Cyclic system simulation
EC	-	Electrochemical
EDL	-	Electrical double layer
EK	-	Electrokinetic
EKA	-	Electrokinetic analyzer
EKP	-	Electrokinetic phenomena
EO	-	Electro osmosis
EOR	-	Enhanced oil recovery
EP	-	Electrophoresis
ERT	-	Electrical resistance tomography
FAWAG	-	Foam assisted water alternate gas
GOR	-	Gas oil ratio
HPLC	-	High performance liquid chromatogaphy
ID	-	Inner diameter
IEP	-	Isoelectric point
IFT	-	Interfacial tension
IHP	-	Inner Helmholtz plane
IOR	-	Improved oil recovery
MRI	-	Magnetic resonance imaging
NIDAS	-	National instrument data acquisition system

OHP	-	Outer Helmholtz plane
PGF	-	Perforations generated foam
PZC	-	Point of zero charge
RP	-	Redox potential
SAG	-	Surfactant alternate gas
SDS	-	Sodium dedocyl sulphate
SedP	-	Sedimentation potential
SLS	-	Sodium lauryl sulphate
SP	-	Streaming potential
SSP	-	Static spontaneous potential
TE	-	Thermoelectric
VSP	-	Vertical seismic profiling
WAG	-	Water alternate gas

LIST OF SYMBOLS

μ	-	Viscosity
μ_{app}	-	Apparent viscosity
μm	-	Micrometer
A	-	Surface area
Al^{3+}	-	Aluminium ion
C	-	Coupling coefficient
Cl^{-}	-	Chloride ion
cm	-	Centimeter
CO_2	-	Carbon dioxide
COOH	-	Carboxylic acid group
cP	-	Centipoises
Cu	-	Copper
CuCl	-	Copper chloride
F	-	Force
f_g	-	Foam quality
g	-	Gram
h	-	Bed thickness
H	-	Hydrogen
k	-	Permeability
l	-	Length
mD	-	Millidarcy
Mg^{2+}	-	Magnesium ion

min	-	Minute
ml	-	Millilitre
mm	-	Millimeter
ms	-	Millisecond
mV	-	Millivolt
N_2	-	Nitrogen
Na	-	Sodium
Na^+	-	Sodium ion
NaCl	-	Sodium chloride
NaOH	-	Sodium Chloride
O	-	Oxygen
ppm	-	Part per million
Q/q	-	Flowrate
q_g	-	Gas flowrate
q_{liq}	-	Liquid flowrate
r	-	Distance from wall to the axis of the capillary
R	-	Lamellae resistance
r_i	-	Inner radius
r_o	-	Outer radius
Rt	-	True resistivity of permeable bed
s	-	Second
S	-	Sulphur
S_{oi}	-	Initial oil saturation
S_{or}	-	Residual oil saturation
S_{wi}	-	Irreducible water saturation
S_{wir}	-	Irreducible residual water saturation
S_{wir}	-	Irreducible water saturation

t	-	Time
V	-	Electrical potential
V_b	-	Bulk volume
V_g	-	Volume of gas
V_l	-	Volume of aqueous dispersion
V_p	-	Pore volume
γ	-	Surface tension
ΔP	-	Pressure gradient
ϕ	-	Porosity

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CHAPTER 1

INTRODUCTION

1.1 Overview

Carbon dioxide (CO_2), nitrogen (N_2), air and hydrocarbon are among the common media used in gas flooding or gas injection. One of the reasons for this is because the primary mechanism of gas injection focuses on displacement efficiency and gas flooding has a better microscopic displacement efficiency compared to water flooding. However, the major challenge when using gas displacement technique is its poor volumetric sweep efficiency. In worst-case scenario, this situation might lead to inexistence of contact between gas and a large area of hydrocarbon in the reservoir (Farajzadeh *et al.*, 2012). The overall hydrocarbon recovery will remain low as a result of this situation.

Ideally, the foam needs to have good stability for it to be considered as alternative solution. Various downhole monitoring techniques have been deployed to minimize reservoir uncertainties, including pressure and temperature sensors, seismic surveys, sonic velocity tools, and resistivity tools. Even though the measured data will be very useful in describing the situation that is happening downhole, the measurements obtained are mostly limited to near wellbore parameters.

4D Seismic can be utilized to provide data in a deeper range of investigation. However, the resolution of the images is rather low. Measurement of electrokinetic potential has been previously proposed as a detecting tool for water encroachment towards a production well (Jackson *et al.*, 2012). The dynamics of electrically charged fluids whether it is formation fluid or injected fluid could be measured by installing permanent electrodes downhole (Jaafar *et al.*, 2009).

In other industry, specifically the paper industry, electrokinetics measurement has been linked to foam, polymers and surfactant (Hubbe, 2006). Since foam, surfactant and polymers are widely used in enhanced oil recovery (EOR) projects; electrokinetic signals could also be measured to predict the efficiency of the recovery mechanisms since EOR will be efficient if the foam is stable throughout the process and surfactant and polymer do not get adsorbed too much along the way.

Dynamic conditions are always going to be ideal for foam formation (Malysa and Lunkenheimer, 2008). The foam half life is determined by the single foam film stability, depending on the physicochemical processes and quantities like surfactant concentration, salt concentration, adsorption kinetics, and gravitational drainage. Other factors such as gas diffusion through foam films, surface forces, capillary pressure and mechanical fluctuations could also be significant (Farajzadeh *et al.*, 2012; Salleh and Ismail, 2012 and Wiggers *et al.*, 2000). Both the formability and stability of foam are the key factors in ensuring high performance of recovery (Qingfeng *et al.*, 2012). Theoretically, electrokinetic potential signal can be correlated with some of these parameters.

Indirect measurement of foam stability using electrokinetic potential is proposed in this study. The aim of this study is to find the relationship between the foam stability in the reservoir and the generated electrokinetic (EK) potentials during the displacement process by using five non-polarizing Cu/CuCl electrodes installed along the sand pack model. A National Instrument Data Acquisition System (NIDAS) was set to record streaming potential and pressure difference data continuously. This system was directly connected to the computer by using LabView software. The rupture of the foam could change the pattern of the EK signal due to the changes in the phases which are flowing through the media.

The correlation between the foam stability and electrokinetic potential could be identified but it will be highly dependent upon the foam film properties and associated characteristics. Under the right circumstances, data obtained in this study could very well be useful in monitoring the macroscopic and microscopic efficiency of an EOR process. Furthermore, by using electrokinetic potential signal, foam stability should be able to be monitored just from the surface conserving time, cost and environment in the process.

1.2 Problem Statement

There are several causes associated with the low recovery problem; gravity segregation because of the large density difference between oil and gas, viscous fingering in which the more viscous oil is by-passed by the less viscous gas and channelling when the gas flows across the high permeable streaks in heterogeneous reservoir (Farajzadeh *et al.*, 2012). Foam flooding, foam displacement process, or foam assisted water alternate gas (FAWAG) has been singled out as a potential solution to overcome these challenges.

Efficiency of the foam displacement process in EOR relies on the foam film stability. Commonly, in laboratory conditions, foam stability is measured through physical observation of the foam bubble production in a glass tube. Unfortunately, this direct observation is impractical to be done in a reservoir. Alternatively, indirect measurement i.e. the measurement of electrokinetic signal is seen as a more viable option. Measurement of electrokinetic signal is thus a promising approach in overcoming the limited range of detection into a reservoir. However, in this study foam stability measurement in the static conditions was also taken into account in order to get a trend of changes between foam stability and Sodium Dodecyl Sulphate (SDS) concentrations which the concentrations ranging from 2500 up to 12,500 ppm. The analysis of the foam stability tests include foam half-life time, surface tension, foam size and pH value.

Streaming potentials in porous media arises from the electrical double layer which is formed at solid-fluid interfaces (Jaafar, 2009 and Hunter, 1988). The solid surfaces are electrically charged, leading to a formation of a stern layer and a diffused layer in the adjacent fluid which contains excess of counter charges. If this fluid is directed by the external potential gradient to flow tangentially to the interface, some of the excess charge within the diffused layer will be transported along with the flow, raising the streaming current. Electrical potential or also known as streaming potential is the result of the amassment of charges which associated with divergence of the streaming current density (Jaafar, 2009).

However, the magnitude and sign of the electrokinetic signal related to foam stability are still considered as significant uncertainties associated with the interpretation of electrokinetic signal measurement. With regards to a FAWAG process, very few studies have reported the electrokinetic for foam. What happen after the foam rupture is also uncertain. Will the electrokinetic increase after the rupture due to the flow becoming more liquid dominant or will it decrease because the flow becoming more gas dominant? This study aims to solve these uncertainties and determine the correlation between the foam stability with the associated streaming potential signals resulted from the flowing fluid in FAWAG processes.

The foam has been produced by in-situ generation in sand pack model by applying the surfactant alternate gas (SAG) foam technique. Electrokinetic signal measurement has been used in this study in monitoring the changes of foam stability by using Cu/CuCl electrodes together with NIDAS and LabView software.

1.3 Objectives

The aim of this study is to further improve our understanding of the correlation between fluid and electrical potentials particularly when foam is present in the system. The study will delve deeper on application of electrokinetic signal in hydrocarbon reservoir monitoring. These goals have been achieved through comprehensive measurements of the electrokinetic signal in a laboratory environment. The specific objectives are:

i. To measure the foam stability in the static environment as a result of the changes in the Sodium Dodecyl Sulphate (SDS) concentration.

ii. To measure the electrokinetic signal as a result of the changes in the foam stability.

iii. To generate a correlation which enables prediction of foam stability based on electrokinetic signals.

1.4 Scope

The scope defines the project limitation and the extent of coverage. The scopes for this project are as follows:

i. Designing a FAWAG process by using sand pack with length and diameter of the model fixed at 30.4 cm and 3.4 cm respectively.

ii. Sodium Dodecyl Sulphate (SDS) was used as a surfactant in FAWAG system in order to enhance the foam stability. The amounts of surfactant added are varied, ranging from 2500 – 12,500 ppm in order to find the ideal foam stability.

iii. The analysis of the foam stability tests are foam half-life time, surface tension, foam size and pH value.

iv. The surfactant alternate gas (SAG) foam technique in FAWAG process was applied in order to produce foam by generating in-situ foam in the sand pack model.

v. Monitoring the changes in electrokinetic potential signal in relation to foam stability by using Cu/CuCl electrodes together with National Instrument Data Acquisition System (NIDAS) and LabView software.

viii. Applying the following conditions: temperature = 22^0C - 26^0C, pressure = 14.7 – 30 psi.

1.5 Significance of the Research

The correlation between foam stability and electrokinetic signals generated in the foam assisted water alternate gas (FAWAG) process presents new findings in this study. This fundamental knowledge could lead to developing new approach in monitoring FAWAG process. The indirect measurement could be very useful for monitoring the efficiency of the enhanced oil recovery (EOR) method in real-time due to low-cost and easy to use monitoring technique. Application in the real field could benefit the oil and gas industry in term of making the EOR process more efficient and more economic. This project could also contribute to better energy and natural resources management.

1.6 Concluding Remark

Chapter 1 explained the details of problem statement, objectives, scopes and significance of the study. Several objectives were withdrawn from this study which are to measure the foam stability in the static environment as a result of the changes in the Sodium Dodecyl Sulphate (SDS) concentration, to measure the electrokinetic signal as a result of the changes in the foam stability and to generate a correlation which enables prediction of foam stability based on electrokinetic signals.

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